Oil and gas accumulations in the Late Jurassic reefal complex of the West Ukrainian Carpathian foredeep

T. S. Izotova & I. V. Popadyuk

Ukrainian State Geological Research Institute,
Mitskevich sq. 8, 290601 Lviv, Ukraine

ABSTRACT

The Cretaceous and Cenozoic Ukrainian Carpathian foredeep basin is underlain by an extensive Late Jurassic, reef fringed carbonate platform. The latter forms part of the extensive system of carbonate platforms which developed during Late Jurassic times on the northern shelves of the Tethys Ocean.

Late Jurassic reefal and back-reef carbonates form the principal reservoirs of 4 hydrocarbon accumulations containing ultimate recoverable reserves of some $37 \cdot 10^6$ bbls of oil and condensate and 1.3 BCF of gas. These fields are contained in two trap types, including erosional highs and roll-over structures related to a major Paleogene erosional phase and subsequent Neogene subsidence of the Carpathian foredeep. Jurassic carbonates and Cretaceous sandstones are the principal objectives in the sub-thrust play of the outer Carpathian nappes. Although the potential of this play has not yet been exhausted, reservoir prediction and reflection-seismic definition of prospects entail considerable risks. Hydrocarbon supply is not considered to be a mayor risk factor in this sub-thrust play.

INTRODUCTION

In the foreland of the Ukrainian Carpathians and beneath their external nappes two oil fields (Kokhanovka and Lopushnya), one gas/condensate field (Letnya) and one gas field (Rudky) were discovered in Late Jurassic carbonates. These fields include additional pay sections in Cretaceous and Miocene sandstones. These fields are under development and contain cumulative ultimate recoverable reserves of $37 \cdot 10^6$ bbls of oil and condensate and 1.3 BCF of gas (Fig. 1). Two blocks containing Jurassic carbonate and Cretaceous sandstone prospects in a sub-thrust position are currently under exploration.

In this paper we address the evolution of the West-Ukrainian Late Jurassic carbonate platform and the habitat of hydrocarbon accumulations asso-

Izotova, T. S. & Popadyuk, I. V., 1996. — Oil and gas accumulations in the Late Jurassic reefal complex of the West Ukrainian Carpathian foredeep. *In:* Ziegler, P. A. & Horváth, F. (eds), Peri-Tethys Memoir 2: Structure and Prospects of Alpine Basins and Forelands. *Mém. Mus. natn. Hist. nat.*, **170**: 375-390. Paris ISBN: 2-85653-507-0.

ciated with it. Although the potential of this Late Jurassic carbonate play has not yet been exhausted, reservoir and seal prediction and reflection-seismic definition of prospects entails considerable risks, particularly in the Carpathian sub-thrust play.

During the Late Jurassic the northern margin of Meso-Tethys was occupied by large reef-bearing carbonate platforms; these extended from the Jura Mountains of France and Switzerland through southern Germany and Poland into the pre-Carpathian domain of the Ukraine and Romania and eastwards via the southern slopes of the Caucasus into Central Asia.

In the western Ukraine, Late Jurassic carbonates occur in the Carpathian foredeep basin and overstep eastwards the Volyn-Podolian margin of the Precambrian East-European Platform (Fig. 1). These carbonates rest on Palaeozoic sediments except in the northwest where they are underlain by a Middle Jurassic siliciclastic series. In turn, the Late Jurassic carbonates are overlain by Cretaceous sediments which, in some areas, are deeply truncated by a Paleogene unconformity. This erosional phase, which is related to the inversion of the Polish Trough and the uplift of the Malopolska Massif of Poland (Ziegler, 1990), resulted in the complete removal of Cretaceous deposits in the northwestern part of the Carpathian foredeep where Jurassic strata are unconformably overlain by Miocene siliciclastic sediments. In the central parts of the Ukrainian foredeep, the so-called Kolomiya palaeo-valley, Mesozoic and Palaeozoic sediments were completely eroded. Elsewhere partially truncated Late Cretaceous sediments are preserved beneath the Paleogene erosional surface (see Sovchik and Vul, this volume).

Late Jurassic carbonates occupy an up to 150 km wide belt in which they attain thicknesses of the order of 500 to 1000 m; a gradual increases in thickness towards the South is evident. In the southern parts of the foredeep, the Late Jurassic carbonates form part of the autochthonous sequence which extends a considerable distance beneath the external nappes of the Ukrainian Carpathian (Fig. 2). Late Jurassic carbonates are located at a depth of about 1 km in the Volyn-Podolia area and at depths of 7-8 km beneath the Carpathian nappes.

STRATIGRAPHY AND FACIES DEVELOPMENT

The stratigraphic framework of the West-Ukrainian Late Jurassic strata was developed by A. Alth (1881), V.I. Slavin (1958), V.Ya. Dobrynina (1961), Ya.M. Sandler (1962), and V.N. Utrobin (1962) The presence of Oxfordian, Kimmeridgian and Tithonian biozones was established by V.G. Dulub (1963, 1964) and later summarized in the stratigraphic scheme of the Jurassic (Dulub et al., 1986). Fig. 3 provides a summary of the lateral facies and thickness changes of litho- and chronostratigraphic units along a selected profile through the West-Ukrainian Late Jurassic Basin.

Oxfordian strata comprise the Rudky and Sokal formations which are lateral equivalents. The Rudky formation consists of oolithic, pelitomorphic and sometimes biohermal limestones which attain thicknesses of up to 150 m; to the southwest these reefal carbonates give way to shaly fore-reef carbonates. The essentially lagoonal Sokal formation is developed in the north-eastern parts of the basin and consists of gray siltstones, shales bearing plant imprints and sandy limestones. Late Oxfordian deposits consist of 10 to 30 m thick multicoloured shaly limestone, containing towards the eastern basin margin intercalations of conglomerates, sandstones and anhydrites.

During **Kimmeridgian and Tithonian** times, progressive subsidence of this shelf was accompanied by the development of a coherent barrier reef, corresponding to the Oparia formation, which consists of gray to light coloured and mottled limestones attaining thicknesses of up to 1000 m. Reef building organisms include corals, sponges, algae, stromatoporides and bryozoans. However, limited core material does not permit detailed facies reconstructions within this reef complex which is basinward offset by thin, deeper water shales and limestones. **Kimmeridgian** back-reef strata correspond to the Rava-Russka formation which consists of a sequence of lagoonal dolomites, dolomitic limestones and anhydrites, ranging in thickness between 20 and 250 m. **Tithonian** back-reef strata are represented by the Nizhnev formation which is composed of light gray and cream

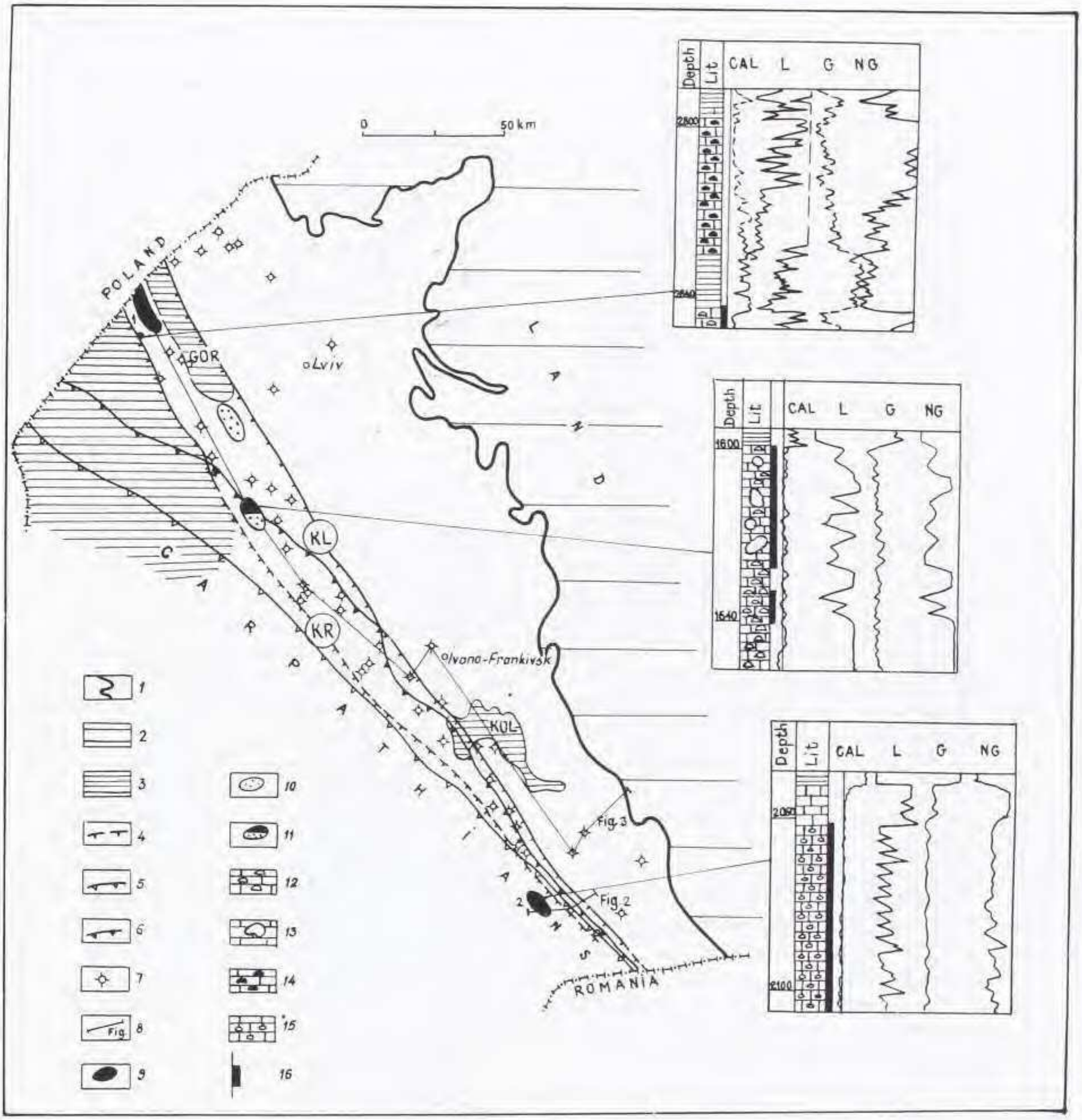

FIG. 1. Regional setting of Late Jurassic basin of Western Ukraine and representative log columns. 1-boundary of basin, 2-area lacking Late Jurassic sediments, 3-area of eroded Late Jurassic sediments (GOR: Gorodok valley, KOL: Kolomiya valley), 4-main normal faults (KL: Kalush-Gorodok, KK: Krakovets-Precarpathian), 5-front of Sambor nappe, 6-front of Boryslav-Pokutian nappe, 7-main wells, 8-trace of cross-sections, 9-oil fields (1: Kokhanovka, 2: Lopushnya), 10-Rudky gas field, 11-Letnya gas/condensate field, 12-boundstone, 13-karstified boundstone, 14-interbedded pelitomorphic limestones , bioclastic, wackestone and packstone, 15-bioclastic limestone, friable wackestone and grainstone, 16-porous intervals.

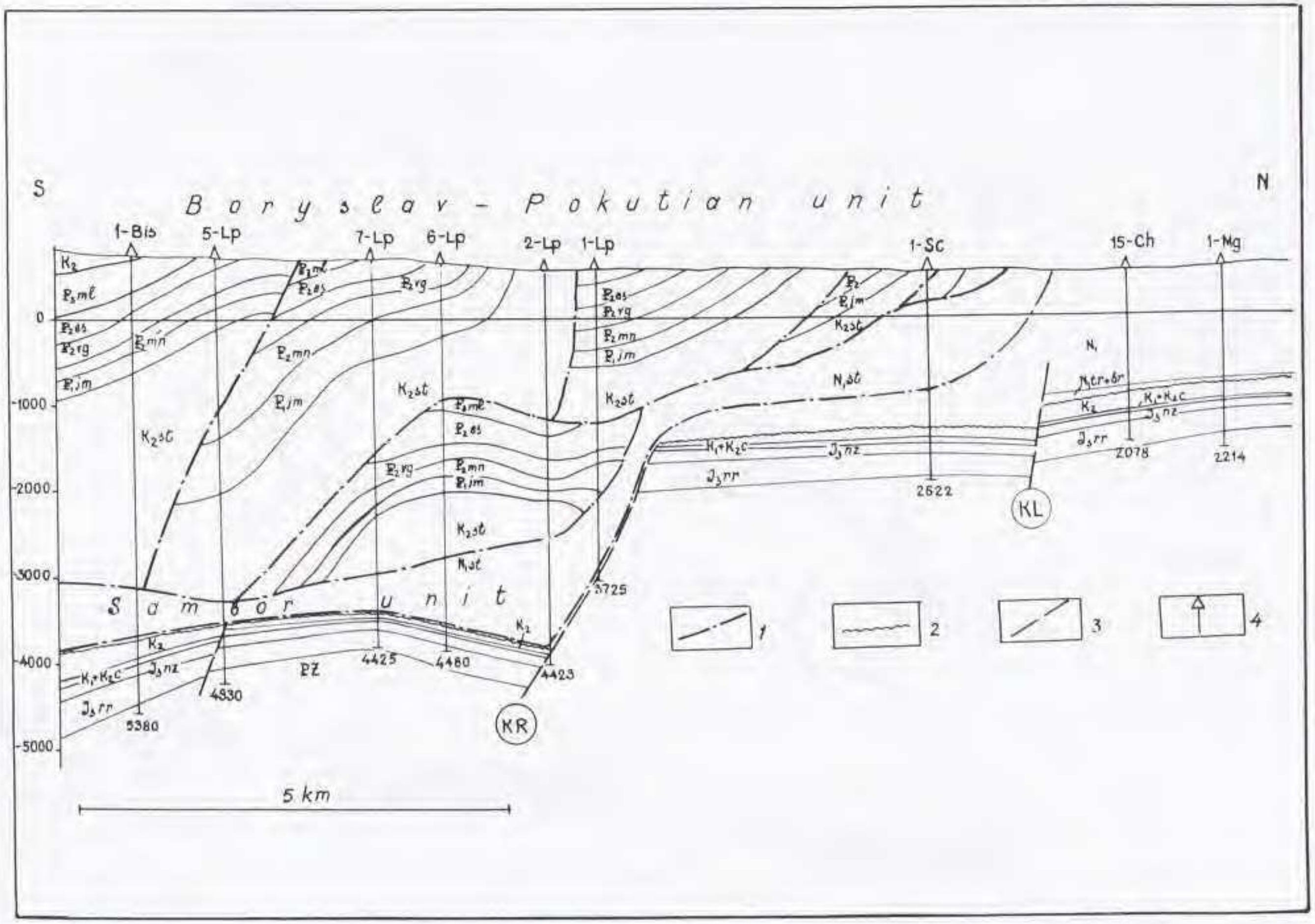

FIG. 2. Geological cross-section through southeastern Carpathian foredeep (for location see Fig. 1). 1-thrust faults, 2-top-Mesozoic erosional surface, 3-normal faults (KL: Kalush-Gorodok, KK: Krakovets-Precarpathian), 4-wells (1-Bis: Biskiv, LP: Lopushnya, 1-SC: Solonec, 15-Ch: Kovalivka-Chereshenka, 1-Mg: Migivska)

coloured detrital and algal limestones attaining a thickness of 200-250 m.

The Jurassic carbonates are conformably overlain by Early Cretaceous shales and limestones. Sedimentation continued through Late Cretaceous times, but was interrupted during the Paleocene and resumed only during the Neogene During the Palaeogene erosional phase, and in conjunction with the Neogene subsidence of the Carpathian foredeep basin, the geometry of the Late Jurassic carbonate platform was modified to such a degree that resolution of its internal configuration by reflection-seismic data meets with considerable difficulties.

METHODS OF INVESTIGATION

For the sub-surface reconstruction of the Late Jurassic carbonate platform the technique of sedimentological analysis of wire-line log data was applied (SALD). This technique relies on the fact that the log response of a rock unit reflects its mineralogical-petrographical composition and texture. As such, also the structural relationship between the different associated rock units could be determined. Based on a quantitative analysis of a suite of petrophysical logs, calibrated by limited core data, a sequence of lithofacies types was identified and their lateral and vertical relationship established. The following types of wire-line logs, which are generally available for exploration wells, were used: micro-lateral, induction, gamma-ray, neutron-gamma-ray, acoustic and caliper (Izotova and Push, 1986; Izotova et al., 1993). Applying the SALD technique, each well was analyzed in an effort to define the different lithofacies types and to establish their stratal succession and their boundaries. Subsequently log correlations between wells were used to develop facies models. The biostratigraphic framework for these sedimentological models.was erected on the basis of palaeontological data obtained from cores.

The SALD technique permits to extrapolate facies interpretations from limited core-controlled data points across the entire basin and thus allows to obtain a better impression of lateral facies and potential reservoir developments. In this respect, the quantitative analysis of wire-line logs in terms of clay content of carbonates, as well as their texture and porosity, are of particular importance. In in order to be able to readily compare the log response of the different lithofacies types, readings were plotted in so-called 8-ray diagrams (Fig. 4). These diagrams give a quantitative range of the response in the usual FSU logging units: gamma-ray (G) in gamma-ray units, laterolog (LAT) and micro-laterolog (ML) in ohmm, sonic (AL) in msec/m. Neutron-gamma-ray (NG) is calibrated in relative units which show the ratio of neutron-gramma activity of the respective strata. Caliper units (CAL) are shown as the ratio between the borehole diameter and the diameter of the drillbit. Porosity (Kp) is presented in % and characterizes the texture of carbonates. The ration of sequence anisotropy (Tk) quantitatively expresses the maximum and minimum deviations of resistivity responses from an average value; conventionally four groups are recognized, ranging from isotropic ($Tk \approx 1.0$) to anisotropic ($Tk < 0.25$). All wireline log parameters utilized for the Tk determination were average-weighted to the sequence thickness. In Fig. 4 the range of these responses are shown in 8-ray diagrams.

Based on an integration of macro- and microscopic core analyses and wire-line data, and following the fundamental work of J.L. Wilson (1980), the Late Jurassic West-Ukraine carbonate shelf was subdivided into nine genetically related lithofacies belts, as summarized in Fig. 4. For each of these facies belts an example of the standard log expression and an 8-ray diagram are given in Figs. 1 and 4. Comparing these 8-ray diagrams, it is obvious that each lithofacies is characterized by its own log response and by the degree of differentiation of the respective logs.

For instance, carbonates which were deposited below the storm wave-base in the fore-reef domain (belts 1 to 3) are characterized by high average gamma-ray readings, high velocities, comparatively low resistivity and an average differentiation of the laterolog and neutron-gamma-ray curves. This is a function of interbedding of carbonates, marls and shales. As reservoir rocks are absent in these facies belts, they are of little interest for oil and gas exploration.

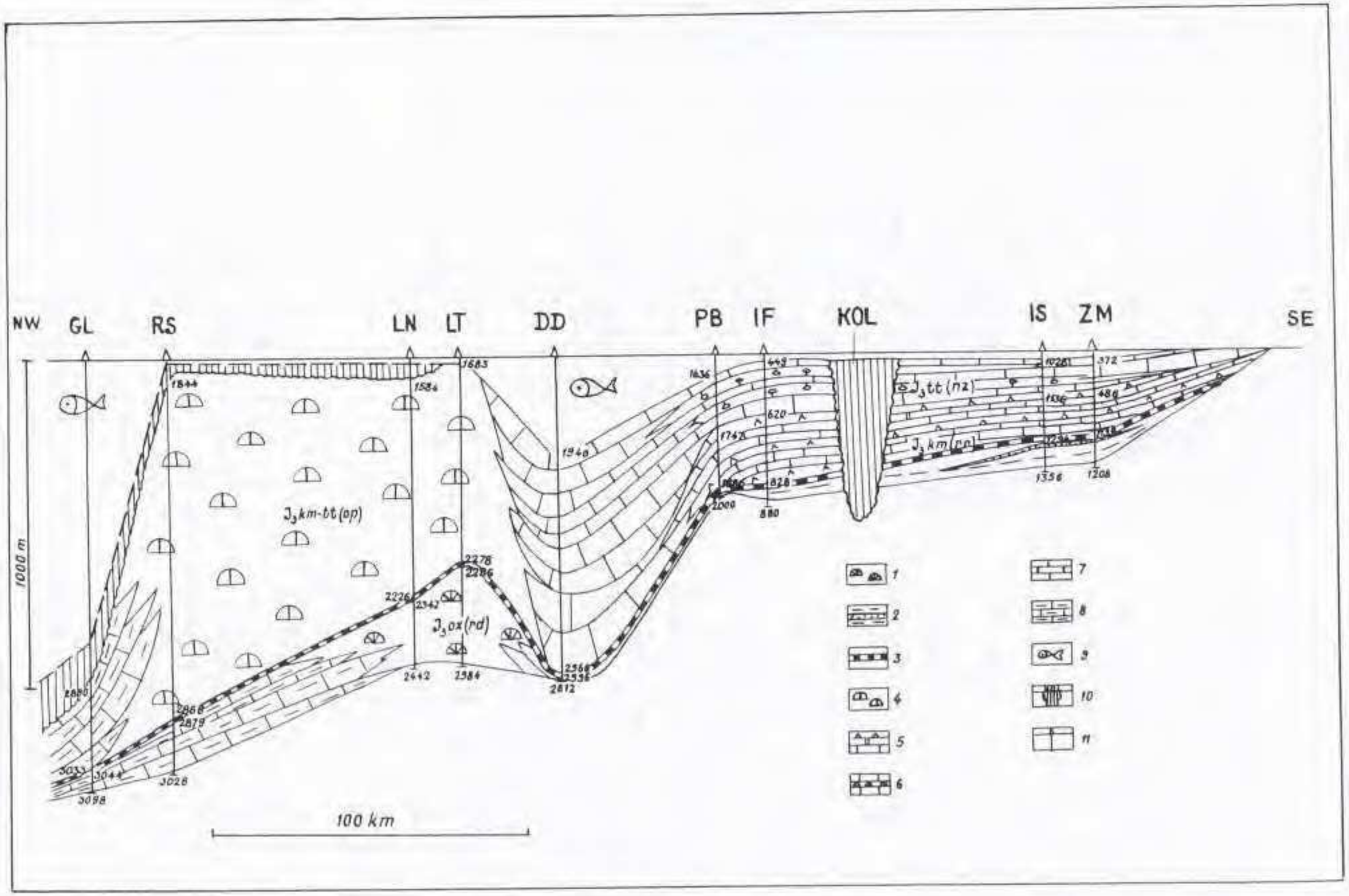

FIG. 3. Reconstruction of Late Jurassic carbonate platform. 1-Oxfordian Rudky reef, 2-Oxfordian shelf facies (Sokal fm.), 3-multicoloured horizon, 4-Kimmeridgian-Tithonian Oparian reef, 5-Kimmeridgian inner shelf and lagoonal facies (Rava-Russka fm.), 6-Tithonian shelf (Nizhnev fm.), 7-back-reef depression facies, 8-fore-reef facies, 9-palaeo-water-depth, 10-erosion during Paleogene (KOL: Kolomiya valley), 11-wells (GL: Gluvin-1, RS: Rosivska-1, LN: Lanivska-1; LT: Letnys-1, DD: Dedushychyn-1, PB: Pivnichni-Bogorodchany-1, IF: Ivano-Frankivsk-1, IS-Ispas-1, ZM: Zamosc-2).

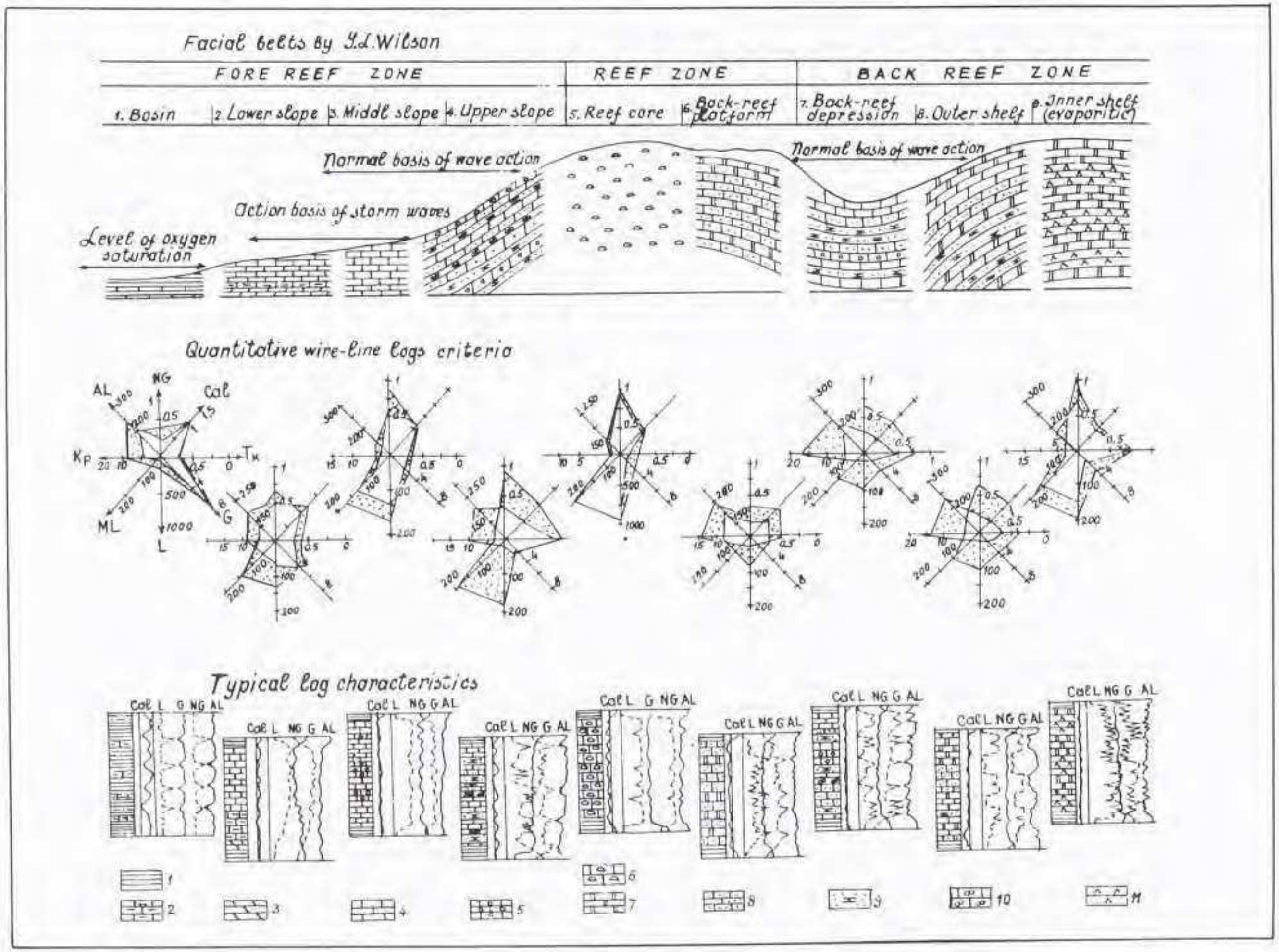

FIG. 4. Quantitative criteria for wire-line facies recognition and representative lithological columns (for explanations see text). 1-shales, 2-shaly limestone, 3-marl, 4-micritic limestone, 5-bioclastic limestone, 6-boundstone, 7-dolomite, 8-grainstone, 9-lime mudstone, 10 limestone breccia, 11-anhydrite.

Reefal carbonates (belt 5), which were deposited under warm, normal salinity, clear water conditions above normal wave base in response to a high bioproductivity, have an extremely low clay content; their gamma-ray response is generally low (not more than 2.5 gammas) and shows little variation. Although the initial texture of these reefal carbonates was partly obliterated by re-crystallization, outlines of framework builders are generally still preserved; therefore, the depositional environment of these carbonates can be determined (Reading, 1990; Wilson, 1980). Carbonates corresponding to the reef core are characterized by the most homogeneous texture and log expressions. Reefal limestones are generally characterized by a high resistivity (1000 Ohmm and greater), high secondary gamma-ray activity and low interval velocities (150 msec/m); natural radioactivity does not exceed 2.5 gammas. All wireline curves are weakly differentiated. A typical log of a reef core, that was not affected by karstification, is given in Fig. 5 for the well Mostovska-2. This section is practically isotropic. These limestones have resistivities of 800 Ohmm, velocities of 150 msec/m and a natural radioactivity of less than 2.5 gammas. The homogeneity of these rocks is interrupted by a porous interval at the depth of 1960-1966 m, possibly corresponding to a grainstone intercalation.

The reef-foreslope (belt 4) and the back-reef shelf (belts 6 to 8) consist of parasequences which are characterized by a variety of limestone facies and textures. Textural variations are reflected by strong variations of Tk. A typical example is provided by the well Lopushnya-4, which is located in facies belt 8. This well penetrated detrital limestones, deposited in normal marine waters, which are characterized by textures ranging from coarse to fine grained. All logs, except the gamma-ray curve, are highly serrated, indicating the presence of several porous intervals in carbonates having a low shale content (Fig. 6). Indeed, the back-reef zone is where the best reservoir developments have been observed with individual reservoirs having porosities in the 5 to 30% range. These reservoirs host the main oil and gas discoveries.

The evaporitic platform (belt 9), consisting of interlayered anhydrites and intertidal dolomites and limestones, has its own characteristic log response (see Fig. 4). The presence anhydrite layers and a high content of shaly limestone downgrades the reservoir potential of this facies belt.

PALAEO-RECONSTRUCTION AND REGIONAL FACIES MODEL

Based on the analysis and correlation of about 300 wells, the evolution of the Late Jurassic carbonate shelf of the West-Ukrainian foreland basin was reconstructed and its hydrocarbon potential further assessed.

In **Oxfordian** times, the Tethys Sea transgressed over the area now occupied by the Carpathian foredeep and advanced across the Volyn-Podolian margin of the Precambrian East-European Craton. During the initial development phase of the West-Ukrainian carbonate shelf, Early Oxfordian shallow marine strata overstepped in the northwestern part of the Ukraine an Early and Middle Jurassic deltaic sequence and gradually transgressed over the margin of the East-European Craton. North of the present day Krakovets fault, a hydroid-coral reef developed, attaining a thickness of 100 m; in back-reef areas, detrital and oolitic limestones, grading shore-wards into the sandy carbonates of the Sokal formation, were deposited. During the Late Oxfordian, reef growth was interrupted, probably in response to a rapid rise in relative sea-level, inducing the accumulation of widespread, 10 to 30 m thick shaly limestones which contain multicoloured horizons and cover the earlier reef complex.

During the **Kimmeridgian**, development of the Oparian barrier reef commenced, slightly basin-ward from the Oxfordian Rudky reefs. The pre-reef parasequences, corresponding to J.L. Wilson's facies belts 3 and 4 (Fig. 4), were only encountered in three wells drilled in the northwestern parts of the basin where they consist of bedded lime-mudstones and litho- and bioclastic calcarenites. The reef core is developed along the Krakovets fault up to where it is crossed by the outer Carpathian nappes. South of this point, the Oparian reef has not been reached by wells; however, its southward continuation beneath the

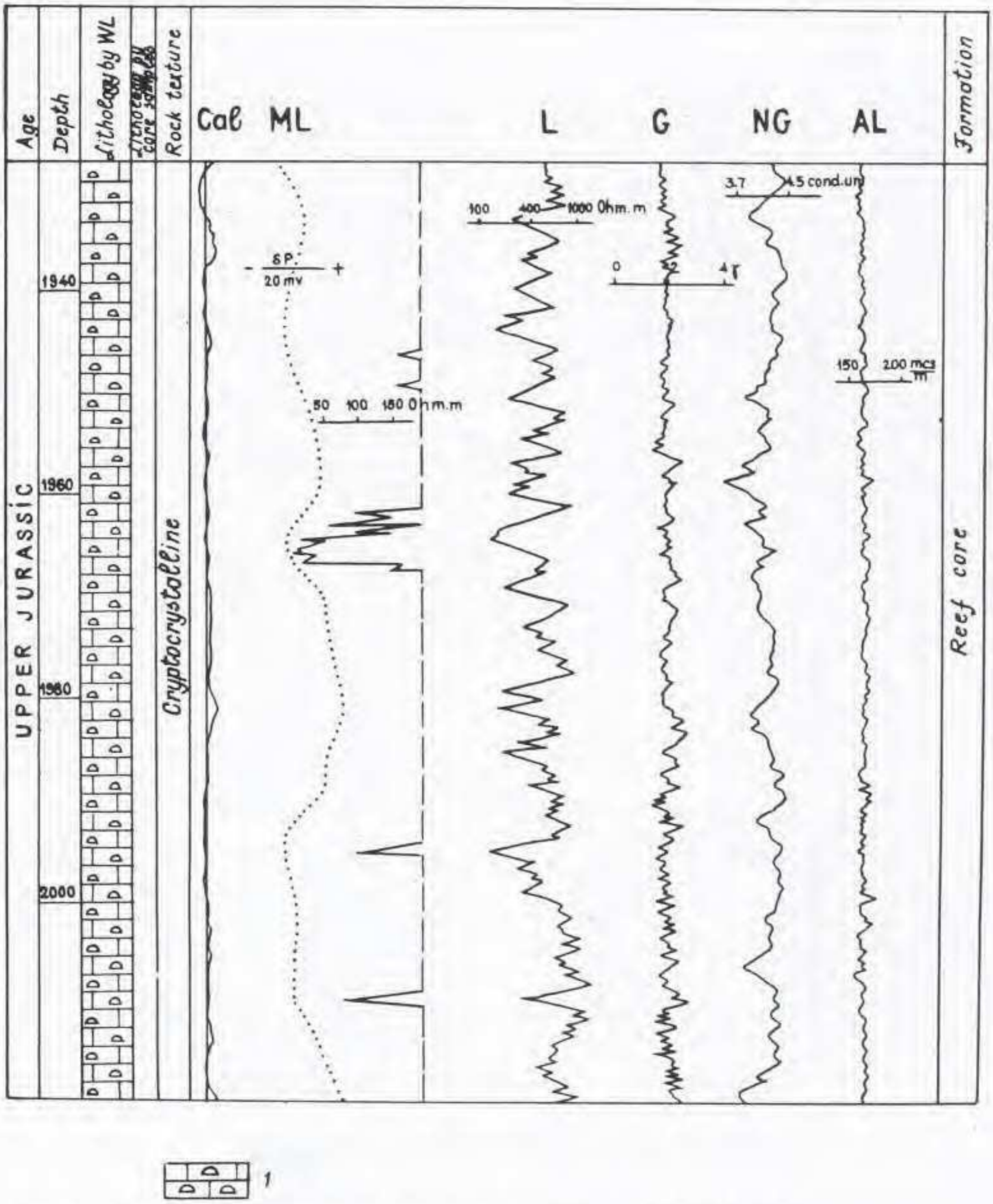

FIG. 5. Wire-line log response of reef-core facies in well Mostovska-2. (1-boundstone)

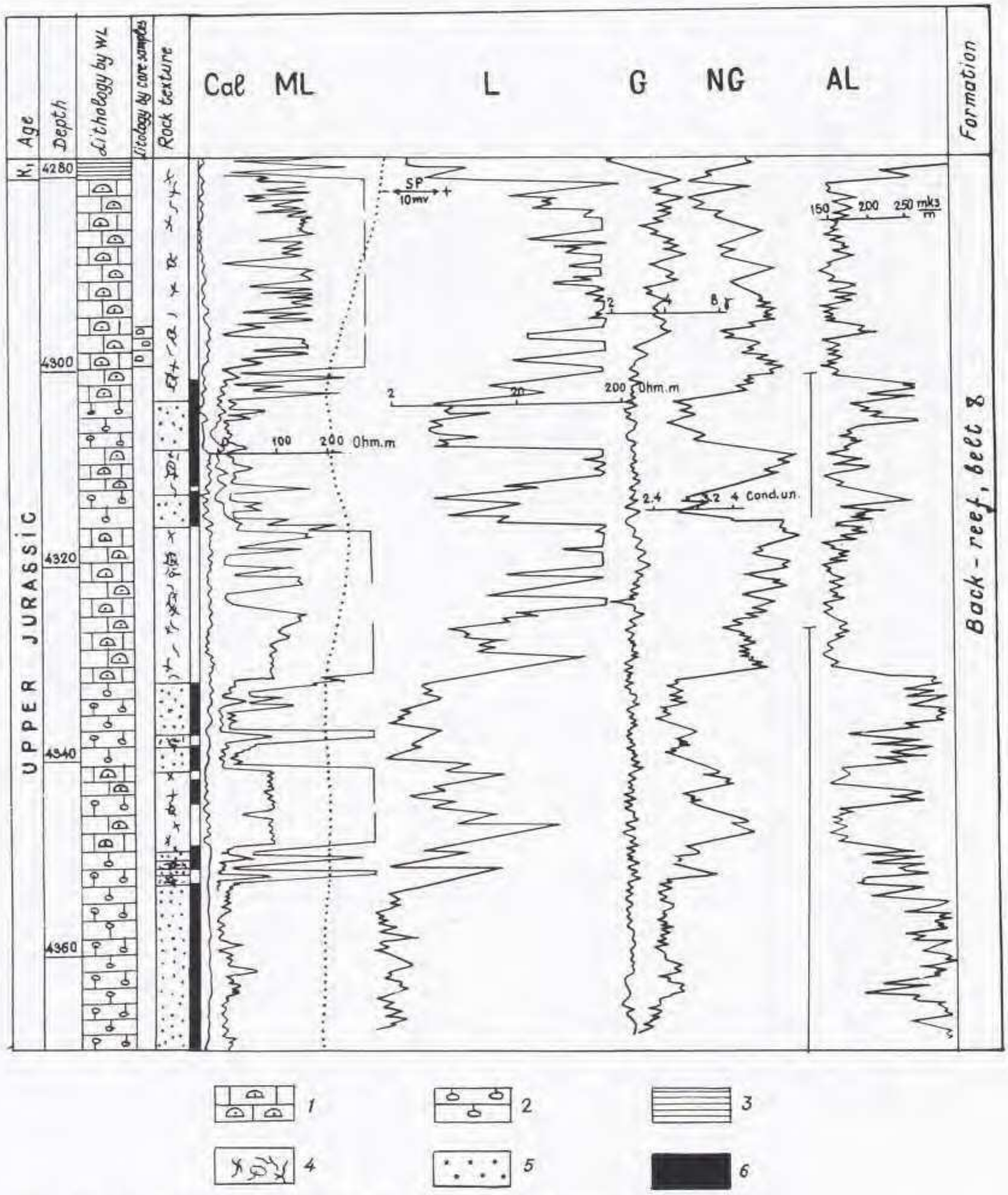

FIG. 6. Wire-line response of back-reef facies (belt 8) in well Lopushnya-4. 1-bioclastic limestone, 2-wacke-, pack- and grainstones, 3-calcareous shales, 4-microvuggy and fracture porosity intervals, 5-intergranular porosity intervals, 6-porous intervals.

Carpathian thrust sheets, at depths of 6 to 8 km, is indicated by reflection-seismic data (Figs. 1 and 7).

Reef growth was accompanied by the development of a relatively narrow, open marine back-reef shelf (facies belt 6) and a deeper water back-reef trough (facies belt 7) which was offset to the east and northeast by an open marine shelf (facies belt 8) grading laterally into a wide lagoonal shelf (facies belt 9). Sedimentation in this lagoon was characterized by a rhythmical alternation of limestones, dolomites and anhydrites, reflecting cyclical changes in water salinity during the deposition of the Rava-Russka formation. Limestones of this parasequence are composed of mud- and sand-sized particles and algal laminites. These were partly dolomitized or anhydritized. Fractured limestones, in part containing micro-vugs, are also encountered. These limestones, which have thicknesses of 10 to 25 m, are interbedded with dolomites and anhydrites. The limestone content of the Rava-Russka formation increases upwards towards its transition to the Nizhnev formation. The gradual decrease in anhydrite intercalations, and their total absence in the Nizhnev formation, indicates a progressive de-restriction of the back-reef lagoon. The limestones of the Nizhnev formation range in texture from mudstones to grainstones. Skeletal remains include bryozoans, coral, sponges and algae. Oolitic and nodular limestones can include a considerable amount of foraminifera.

During the **Late Tithonian**, environmental conditions became more uniform, probably due to a slight deepening of the basin and decreasing reef growth (decreased bioproductivity). Throughout the Ukrainian part of the Late Jurassic shelf, thick, regionally correlative bioclastic carbonates were deposited. These prograded towards the deeper waters back-reef trough. On Figs. 3 and 4 the white area shown behind the Oparian reef reflects the remnant water depth prior to deposition of the Early Cretaceous sediments. In the central parts of the Late Jurassic back-reef remnant trough, Tithonian carbonates are conformably overlain by Early Cretaceous limestones, containing some thin shale intercalations; to the East, these limestones give way to shales with clastic intercalations.

HYDROCARBON HABITAT

Source Rocks

Geochemical analyses of source-rocks are a traditional Achilles heel of Ukrainian geologists, particularly of the older generation. Therefore, special publications addressing the geochemistry of hydrocarbons contained in Late Jurassic reservoirs are lacking. However, based on regional geological considerations, we assume that possible source-rocks, which may have charged Late Jurassic reservoirs with liquid hydrocarbons, may be associated with the deltaic Middle Jurassic sequence of the northwestern parts of the foredeep whereas in its southeastern parts the Oligocene Menilites shales may be the primary source-rock. The gas contained in the Rudky and Letnya fields is probably of biogenic origin generated in Miocene strata. In view of the lack of reliable and up-to-date data we must desist from further discussions and speculations on this subject.

Reservoir Development

In view of strong lateral facies variations in the Late Jurassic carbonates, development of commercially viable reservoirs is very variable and differs in origin in the different facies belts.

Within the reef core, depositional interskeletal vugs and cavities are not preserved due their infilling with lime muds and subsequent re-crystallization. However, karstification of the reef core during the Paleogene erosional phase and as a result of sub-surface water circulation, caused the development of good reservoir porosities and permeabilities. Moreover, there is evidence for intra-Jurassic early leaching porosity developments.

In back-reef areas (facies belts 7 and 8) the best reservoirs are associated with friable limestones which are characterized by various textures, ranging from mudstones to grainstones. Of special interest are algal laminites which are very porous and intensely fractured (Markovsky et al., 1991).

Source : MNHN, Paris

Secondary reservoirs are provided by Early Cretaceous, Cenomanian and Miocene sandstones.

Seals

Early Cretaceous shales provide a sub-regional seal for Late Jurassic carbonate reservoirs. The sealing capacity of the anhydrites occurring within the Rava-Russka formation has not been established. Miocene shales and evaporites provide seals for Jurassic carbonates subcropping the Paleogene unconformity. In the southeastern part of the Carpathian foreland basin, shales of the flysch nappes, which are thrusted over Paleogene erosional surface, can provide effective seals for the autochthonous Mesozoic reservoirs (Fig. 7).

Traps

Established hydrocarbon accumulations are contained in two trap types, namely erosional highs and low-amplitude roll-over structures (Fig. 7). Both trap types are associated with the Paleogene erosional phase and the subsequent development of the Carpathian foredeep basin during which the structural configuration of the West-Ukrainian Late Jurassic carbonate shelf was profoundly modified.

During the Paleogene the entire area was raised above the erosional base level, resulting in the development of a southerly trending drainage system, as evident by the incision of palaeo-river valleys. Some of these cut through the Cretaceous and Late Jurassic strata and even into the underlaying early-Middle Jurassic and/or Palaeozoic sediments (see Sovchik and Vul, this volume). In the northwestern parts of the area, where Cretaceous sediments were completely removed during this erosional phase, Late Jurassic carbonates, both of the reefal and back-reefal type, uphold elongate palaeo-topographic highs. These were onlapped by transgressive Miocene shales and sandstones. The Badenian Baranivska shales and the Tyrassian gypsum and anhydrites provide effective seals for the Jurassic carbonates. Accumulations of this "sub-Badenian" type, which produce from Jurassic carbonates and Miocene sands, are the Rudky gas field, the Letnya gas/condensate field and the Kokhanovka oil field (Fig. 7)

Although development of the Neogene Carpathian foreland basins was accompanied by fault-controlled down-flexing of the foreland, this type of normal faulting was not as diffuse as for instance in the Austrian part of the Molasse basin, where it led to the development of a large number of mainly antithetic fault traps (fault throws of the order of 100-200 m; Kollmann and Malzer, 1980), but was concentrated on a few major faults. Amongst these, the Krakovets fault with a synthetic normal throw of 3000 m is the most important one (Fig. 2). So far no traps associated with Neogene normal faults have been established in the Ukrainian part of the Carpathian foreland basin. However, several low amplitude anticlinal roll-over structures are associated with the footwall block of the Krakovets fault; such a structures form the traps of the Lopushnya oil field (Figs. 2 and 8).

Beside the established trap types, there is some scope for additional traps. For instance, within the back-reef area between the Krakovets and Kalush faults, seismically mappable buried hill features occur which are upheld by the relief of the base Late Jurassic unconformity. These palaeotopographic anomalies, which have amplitudes of about 200 m, influenced sedimentation during the deposition of the Late Jurassic carbonates and, due to compaction drape, are also evident at Early and Late Cretaceous structural levels. To the southwest of the Krakovets fault some potential traps may be associated with the depositional configuration of the Oparian reef trend. In this area the reef envelope has a relief of 400 to 600 m towards the back-reef area and some 800 m towards the fore-reef area where sedimentation rates were considerably smaller than the bioproductivity in the reef core. Lateral variations in reef height and/or Paleogene valley incisions may provide for a wide range of possible traps, located at depths of 7-8 km beneath the Carpathian nappes. Some of these prospects are seismically mappable.

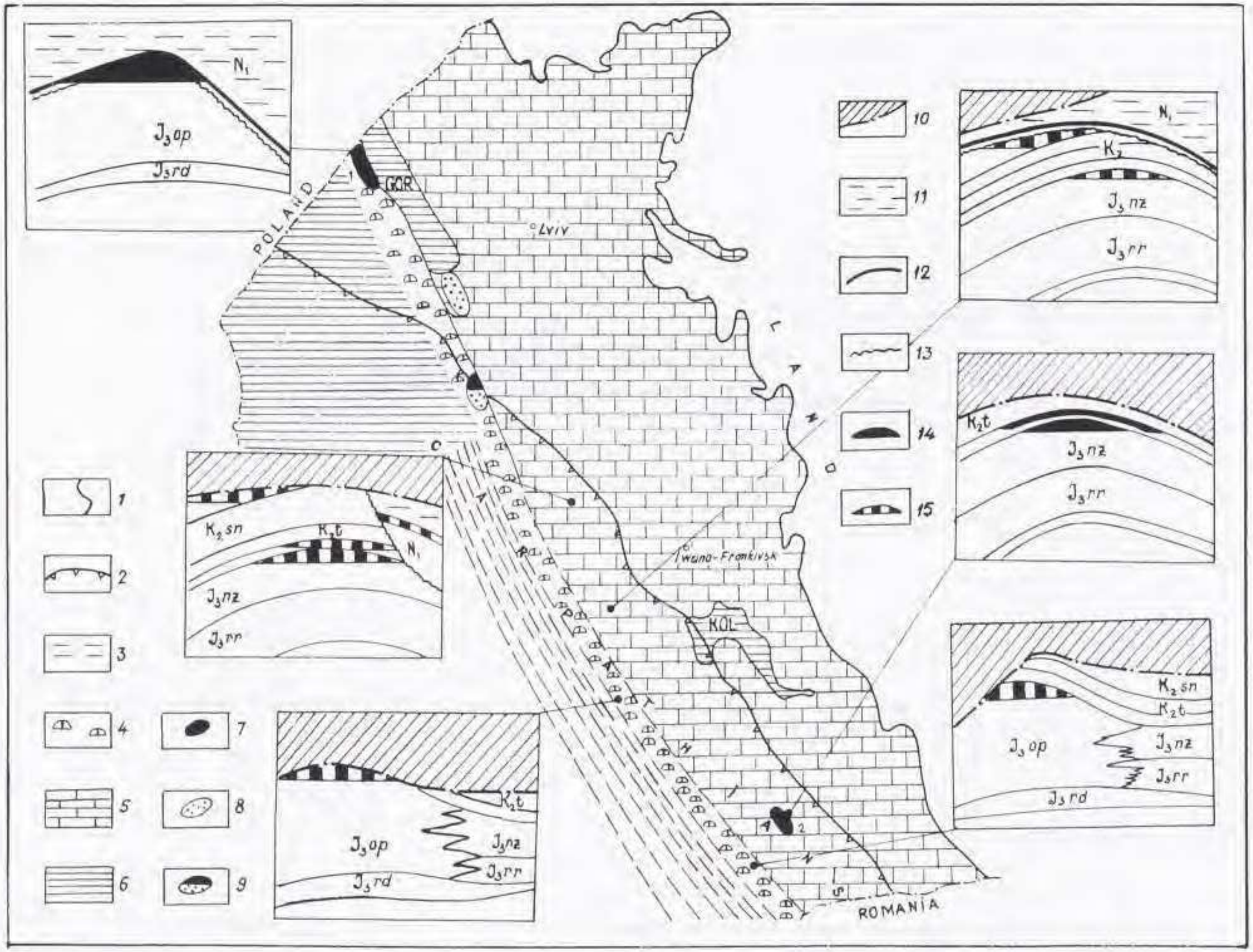

FIG. 7. Late Jurassic facies distribution and summary of established and potential Mesozoic trap types in the Carpathian foredeep. 1-boundary of Late Jurassic carbonate platform, 2-Carpathian nappe front, 3-fore-reef zone, 4-barrier reef complex, 5-back-reef zone, 6-area of eroded Late Jurassic sediments (GOR: Gorodok valley, KOL: Kolomiya valley), 7-oil fields (1: Kokhanovka, 2: Lopushnya), 8-Rudky gas field, 9-Letnya gas/condensate field, 10-nappes, 11-autochthonous Neogene, 12-Badenian seals, 13-top-Mesozoic erosional surface, 14-established fields, 15-potential traps.

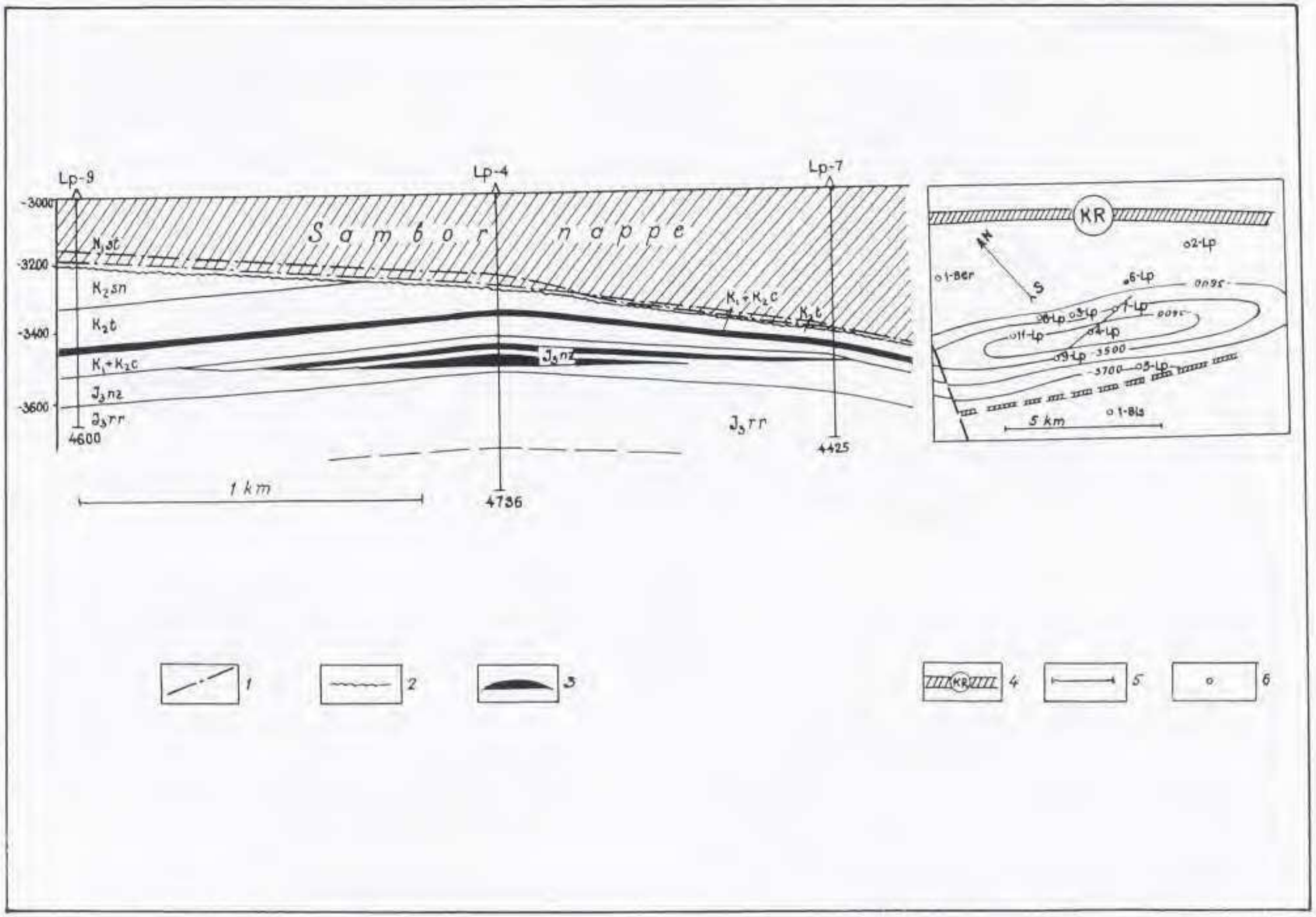

FIG. 8. Lopushnya oil field, cross-section and top-Jurassic structure map. 1-Sambor nappe sole-thrusts, 2-top-Mesozoic erosional surface, 3-pay zones, 4-Krakovets-Precarpathian regional fault, 5-cross-section line, 6-wells (LP: Lopushnya-, 1-Ber: Beregomet-1, 1-Bis: Biskiv-1).

OIL AND GAS FIELDS AND REMAINING HYDROCARBON POTENTIAL

Between 1940 and 1950 the Rudky gas field and the Kokhanovka oil field were discovered in the northwestern part of the Ukrainian Carpathian foredeep basin. Somewhat later the Letnya gas/condensate field was found in the same area. All three fields are of the sub-Badenian type and produce from Jurassic carbonates and onlapping Miocene sands. The Late Jurassic reservoirs of the Kokhanovka and Letnya fields consist of karstified reefal limestones of the Oparian formation which were eroded and leached during the Paleogene erosional phase to form erosional highs. Porosities reach 20%, permeability is fracture enhanced and pay thicknesses range up to 20 m. The Rudky field produced from karstified back-reef carbonates.

In 1984 the Lopushnya oil field was discovered in a sub-thrust position in the southeastern part of the Carpathian foredeep (Fig. 8). It established production from Jurassic carbonates and Cretaceous sands, forming part of the autochthonous Mesozoic sequence, which are involved in an anticlinal structures having an amplitude of some 200 m. This structure is clearly evident on reflection-seismic data. Production comes from Early Cretaceous and Cenomanian sandstones and Late Jurassic carbonates, sealed by Cretaceous shales.

Initial production from the Jurassic reservoir of well Lopushnya-4 amounted to 1130 bbls/day. This reservoir is formed by partly dolomitized lime-mudstones and grainstones as well as by algal limestones, characterized by abundant micro-vugs and fractures, of the Nizhnev formation which is here developed in facies type 8. Fig. 6 provides logs for the productive carbonate interval of well Lopushnya-4. Porosities of productive intervals are in the 8-20% range; the best reservoirs are formed by friable limestones which make up about 80% of the pay section.

In the entire southeastern part of the Ukrainian Late Jurassic carbonate shelf the Nizhnev formation is the prime objective horizon. Net reservoir thicknesses range between 10 and 60 m and are mainly tied to friable and micro-vuggy algal limestones.which have a regional distribution and are only lacking in Paleogene palaeo-valleys where the Nizhnev formation was partially or totally eroded.

In the vicinity of the Lopushnya field, seismic surveys permit to map a number of similar structural prospects beneath the Carpathian nappes.at depth of 5 to 7 km. To the south of these highs, reefal build-ups are expected which are encased in Early Cretaceous shales; the latter are only partially truncated by the Paleogene unconformity and are sealed by the Carpathian Sambor and Borislav-Pokutian flysch nappes. In the northern parts of the external Carpathians, where the Oparian reefs were stronger exhumed by Paleogene erosion, additional prospective structures have been mapped at the Jurassic objective level in a sub-thrust positions. However, despite of visible progress in the development of the sub-thrust play, it is still poorly evaluated, mainly due to insufficient reflection-seismic control. It is questioned whether a possible charge risk is a serious down-grading factor for this area. Yet, the integrity of sealing horizons may present a potential risk factor, as indicted by the failure of the recently drilled Tatalivke and Petrovets wells.

To the North of the Carpathian nappe front some prospects of the sub-Badenian type are recognized. Two of these were tested by the recently drilled exploration wells Vyzhomla-1 and Tyniv-2, located to the northwest of the Letnya gas/condensate field; both wells tested oil from karstified Jurassic carbonates.

It is concluded that the Ukrainian Carpathian foredeep still holds promising prospects, particularly in the sub-thrust autochthonous Mesozoic series. These warrant further evaluation by reflection-seismic detailing and drilling. The model presented for the Late Jurassic carbonate shelf and its reservoir potential requires further refinement as new core data becomes available.

Acknowledgements- The authors express their gratitude to the *American Association of Petroleum Geologists, Shell Internationale Petroleum Maatschappij B.V.* and personally to Dr. D.L. Loftus and Dr. P.E.R. Lovelock for sponsoring their participation in the AAPG Conference in Den Haag. Thanks are extended to Dr. P.A. Ziegler for critical and constructive comments on a first draught of this manuscript and for his editorial efforts.

REFERENCES

Alth, A. (1881), *Nizhnev limestone and its fossils*. Cracow Academy of Knowledge, Vol VI, Cracow (in Polish).

Dobrynina, V.Ya. (1964), "Jurassic sediments of southwestern margin of Russian Craton and Precarpathian foredeep". *Technical Report of USSR conference on stratigraphy of Mesozoic sediments of Russian Craton. Vol. II, Jurassic. Gostoptechizdat, Leningrad*, pp. 154-161 (in Russian).

Dulub, V.G. (1963), "Problem of Oxfordian-Kimmeridgian boundary of southwestern margin of Russian Craton". *Collected reports of UkrNIGRI, Nedra*, pp. 251-258 (in Russian).

Dulub, V.G. (1964), "Jurassic multicoloured sediments of Volyn-Podolian margin of Russian Craton". *Collected reports of UkrNIGRI, Nedra*, pp. 101-105 (in Russian).

Dulub, V.G., M.I. Burova, V.S. Burov and I.B. Vishnyakov (1986), *Explanatory notes to the regional stratigraphic scheme of Jurassic deposits of the Precarpathian foredeep and Volyn-Podolia margin of the East-European Craton*. VSEGEI Publ. House, Leningrad, 58 p. (in Russian).

Izotova, T.S. and A.O. Push (1986), "Sedimentological log analysis - the framework for geological section prediction". *Rept. UkrSSR Acad. Sci., Kiev, Ser. B*, No 10, pp. 7-11 (in Russian).

Izotova, T.S., S.B. Denisov and B.Yu. Vendelshtein (1993), *Sedimentological analysis by wireline log data*. Nedra, Moscow, 120 p. (in Russian).

Kollmann, K. and O. Malzer (1980), Die Molassezone Oberösterreichs und Salzburgs. In *Erdöl und Erdgas in Oesterreich* (Edited by Bachmayer, F.). Naturhistorisches Museum, Wien, pp. 179-201.

Markovsky, V.M., T.S. Izotova, V.M. Bortnitska, T.A. Baranova and A.O. Push (1991), "New type of carbonate reservoir in Upper Jurassic of Bilche-Volitsa zone of Precarpathian foredeep". *Collected reports of UkrGGRI, Lviv*, pp. 87-93 (in Russian).

Reading, H. (1990), *Sedimentary environment and facies. Russian Translation from English*, Mir, Moscow, Vol 2, 384 p.

Slavin, V.I. and V.Ya. Dobrynina (1958), "Stratigraphy of Jurassic sediments of the Lvov depression and Precarpathian foredeep". *Bull Moscow Naturalist Soc., Geological Division*, **XXXIII**, 2, pp. 43-54 (in Russian).

Utrobin, V.N. (1962), "Main features of Jurassic stratigraphy of Precarpathian foredeep and southwestern part of Russian Craton". *Rept. USSR Acad. Sci.*, **147**, 4, pp. 908-911 (in Russian).

Wilson, J.L. (1980), *Carbonate facies in geological history. Russian Translation from English*. Nedra, Moscow, 463 p.

Ziegler, P.A. (1990), *Geological Atlas of Western and Central Europe, 2nd*. Ed. Shell Internationale Petroleum Mij. B.V. and Geol. Soc. Publ. House, Bath. 239 p.